Oil Painting Assistance Using Projected Light: Bridging the Gap Between Digital and Physical Art

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Figure 1: (a) Painting studio setup (b) Painting a layer in *preview mode* (c) Painting the black regions of a layer in *color selection mode* (d) Final painting created using our system

Abstract

This paper presents a novel interactive system for guiding artists to paint using traditional media and tools. The enabling technology is a multi-projector display capable of controlling the appearance of an artist's canvas. Artists are guided by this display-on-canvas to execute painting techniques. The artist paints according to a linear process of painting by numbers, one layer at a time. Each layer is painted using a set of interaction modes. Preview mode shows the entire layer as the current painting goal. Blank mode shows the state of the painting. Color selection mode displays where to paint a certain color, orientation mode shows how to paint it, and texture highlight mode enhances the texture of the paint following its application. These interaction modes enable the novice to focus on painting sub-tasks in order to simplify the painting process while providing technical guidance ranging from high-level composition to detailed brushwork. In addition to assisting artists for painting, we discuss how our system could be extended to sculpture, woodwork, and other areas of the fine arts.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction Styles I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture—Radiometry

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1 Introduction

Throughout history, the human desire to create art has produced a rich field of techniques and technologies for supporting artistic painting. In this paper, we present an interactive painting system to support the everyman artist, novice or expert, in creating art using traditional media and tools. In contrast with other computer painting systems that provide tools for digital image synthesis, this work focuses on guiding users to paint according to classical techniques for creating *paintings as objects*, not just images. By employing multiple projectors to create an interactive display on the artist's canvas, the system presented in this paper is capable of augmenting a painting in progress with visualization features to preview artistic decisions and assist with technical details such as brushstroke position, orientation and texture.

Our system is part of a long history of tools for reflecting and capturing the perspective and shading of a scene as a first step in establishing the structure of a painting. Perhaps the most well-known of such tools is the *camera obscura*, a dark box or room with a hole or lens in one end used for projecting a scene onto a surface. Recently, geometric analyses of paintings by Johannes Vermeer supported the theory that he used a camera obscura to produce such realistic and geometrically accurate paintings [Steadman 2002]. The modern descendant of the camera obscura is the *art projector*, an opaque projector sold in most major art stores. By replacing the art projector with video projectors and a camera, we propose using visual feedback to guide the user through the steps that follow toward creating a final desired painting.

As traditionally taught in art classes, the painting process is divided into a series of sub-paintings, defined as a set of layers. Our claim is that a beginning artist may successfully complete a complex paint-

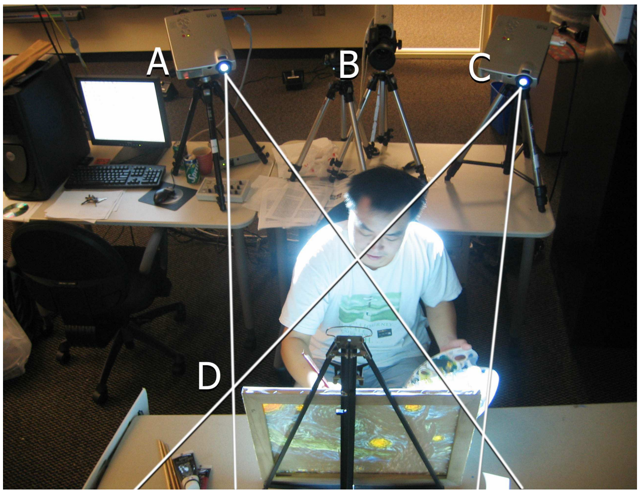

Figure 2: An artist painting with the aid of our system. Projectors A and C illuminate the canvas, D, while the camera, B, is used for both geometric and photometric calibration.

ing by focusing on one layer at a time. The key to enabling a novice painter to manage a layer-based approach to painting is the ability to control the appearance of the canvas to the artist. Projectors are used to create a display that is capable of adapting to the canvas as it is being painted. For example, the illusion of a blank canvas can be created at any point throughout the painting process. Furthermore, the ability to switch between layers is at the fingertips of the artist. By interactively manipulating the appearance of layers, a painter may not only display the next layer by itself, but preview succeeding layers building up to the complete painting.

The painting assistance techniques presented in this paper employ a multi-projector adaptive display for minimal intrusion on the traditional painter's environment. The display is formed by aligning multiple overlapping front projectors. As shown in Figure 2, each projector is positioned to the sides of the artist to help minimize occlusions between the light rays and canvas which cast shadows onto the display. The design of our display is based on previous work on using multiple projectors for shadow removal [Cham et al. 2003]. Following a geometric calibration step, each pixel on the display may be illuminated by multiple rays of light to support the ability of our display to adapt to the paint on the canvas. We apply the photometric adaptation technique of [Grossberg et al. 2004; Nayar et al. 2003] and leverage the illumination redundancy provided by multiple projectors to increase the dynamic range and, consequently, the adaptability of the display to the painted surface. Our domain is a challenging one for adaptation because the canvas is continuously changing throughout the painting process and the presence of wet paint results in specular surfaces. We note that projecting onto the canvas from behind is not an option when opaque paints such as oil and acrylic are used.

In this paper, we make the following contributions:

- A novel interactive system for guiding artists to paint using traditional methods and tools.
- A novel method for creating virtual paint on a previously painted canvas, which allows artists to paint each layer without being distracted by the layers underneath.
- A set of interaction modes for a canvas-centric interface which supports a traditional layer-based approach to painting.

1.1. Related Work

While there is a long line of work in painterly rendering for digital images [Haeberli 1990; Meier 1996; Curtis et al. 1997; Salisbury et al. 1997; Hertzmann 1998; Hays and Essa 2004] and the simulation of traditional media and tools for art [Baxter et al. 2004; Baxter et al. 2001], to our knowledge there have only been a few systems, interactive or automatic, for creating art as objects using physical tools. A robotic painting system named AARON [McCorduck 1990] has been actively developed for three decades and its paintings have been featured in several museums and art galleries.

The Everywhere Display (ED) demonstration at Siggraph in 2001 [Pinhanez et al. 2002] guided users to create "paintings" on a table out of a collection of M&Ms, where each M&M candy served as a pixel in the image. Users were instructed to place a single M&M in a specific spot under the guidance of projected light superimposed on the M&M image. In contrast, our system is designed to support a fundamentally creative process within the framework of traditional painting practice.

Other researchers have used projector-camera systems to support spatially augmented reality [Raskar et al. 1998]. Shader lamps [Raskar et al. 2001], for example, used multiple projectors to illuminate complex models, such as the Taj Mahal, or animate static objects, such as toy cars, thereby treating projectors as "shaders" for real-world objects. In contrast to these applications, however, the goal of our system is to create art using traditional media in a computer-assisted way. Our compensation approach is based on the method of [Grossberg et al. 2004; Nayar et al. 2003], which addressed the problem of projecting onto photometrically non-uniform surfaces.

2 Process of Painting

The versatility of oil and acrylic paint as an artistic medium has led to the development of highly refined processes and techniques for expressing a wide variety of artistic styles. These processes range from the quick freeform application of wet-into-wet, as in the Alla Prima technique for impressionism [Smith et al. 1995], to the painstaking 7-layer Flemish method, a classically realist style with drying periods of months between each layer. Coupled to these wide variations in the strategy for building up a painting is an equally wide range of methods for applying paint to canvas, from precisely controlled strokes or dots to the 'drip and splash' approach that characterizes Jackson Pollock's work.

In this section we present the rationale that underlies the design of our interactive system and describe the interaction modes that define its use by an artist. The design of our system is based on the following two assumptions about the process of painting in acrylics and oils:

- We assume that paintings will be planned out in advance of execution and decomposed into a series of layers that can be applied to the canvas in linear order (back to front).
- When painting each layer, we assume that the artist will want to apply paint to the canvas in an orderly, sequential manner and will base their palette on the color scheme for the layer and the desired amount of manipulation.

Thus our system provides support for the decomposition of a painting into layers and for the selection, application, and manipulation of paint during the execution of each layer.

We had two goals in designing our system: First, we wanted to teach and encourage novice artists to paint with good technique.

Figure 4: Clockwise order from upper-left: (a) Sphere with highlight and shadow (b) Coarse blending with bristle brush in orientation mode (c) Fine blending with fan brush in orientation mode (d) Smooth sphere following blending

Second, we wanted to increase the artist's enjoyment of the process of painting by addressing standard pitfalls and frustrations that often arise. Our system has the flexibility to handle a wide range of painting styles and approaches. Portraiture, still life, and landscape paintings are examples of domains that are supported by our process model. However, Jackson Pollock's paintings provide an example of a less traditional means of applying paint that does not fall within the range of techniques that we currently support.

2.1. Interaction Modes

Our system is designed around a set of interaction modes that assist the artist in painting the ordered set of layers that comprise a finished painting. We support hands-free switching between interaction modes using a foot pedal (see included video for example usage). Each interaction mode is realized by projecting light onto the surface of the painting itself and compensating for the existing paint in creating the desired display. We describe our adaptive projected display in detail in Section 4. The following list includes the five painting interaction modes provided by our system.

- **Preview Mode** to display layers
- **Color Selection Mode** to view specific colors
- **Blank Mode** to assess the state of the painting
- **Orientation Mode** to display brushstroke directions
- **Texture Highlight Mode** to enhance the painting's texture

Our decision to focus the design of our interactive system on a layer-based approach to painting is informed by common difficulties that beginning painters may encounter in learning how to paint. As described in [Gair 1998], inexperienced painters often make the mistake of working on one small area of a painting until it is 'finished' and then move on to the next area. This can result in a "confused and disjointed image because each area of tone and colour is separate and unrelated to its neighbors." Gair suggests heeding the advice of Cézanne: "start with the broom and end with the needle!".

Furthermore, this approach also corresponds with the specific oil painting principle of working 'fat over lean' for the wet-into-dry method of painting: "the paint should be thinly diluted with turpentine and allowed to dry thoroughly before adding further layers." If too many heavy layers of paint are applied in the early stages, the surface may quickly become clogged and the paint "builds up to a slippery, churned-up mess."

To support the task of building a painting step-by-step or one layer at a time, the artist may work in *preview mode* to display the current layer in progress while compensating for the underlying paint as shown in Figure 1b. Areas of the canvas that are not to be painted in the current layer are hidden from the artist using a checkered pattern that may be easily distinguished from the foreground elements of the layer. This reduces the chance that regions outside the current layer will distract the artist from a particular execution step.

Furthermore, the clear visibility of all layer regions and "invisibility" of off-layer regions provided in preview mode helps the artist devise a strategy for selecting a color palette and set of brushes that are used to paint the layer. For example, in the case where layers are automatically generated using a painterly rendering system, each layer corresponds naturally to one specific brush size. It is easy to select a brush in preview mode by physically comparing brushes to their previewed strokes on the canvas.

Another challenge in executing a particular layer is the efficient use of paint. An artist with a loaded brush would like to quickly identify regions of the canvas that need that particular color. To address this need, we designed a *color selection mode* that highlights all strokes of a chosen color in the current layer. The artist uses a Wacom tablet with a pen attached to the opposite end of the paintbrush (see Figure 1b) to select a specific color in the layer. Following color selection, all other colors are hidden from view so the artist can apply the color where defined in the layer. Figure 1c shows that color selection mode clearly outlines the color at hand while hiding the other details of the layer. For areas of the layer such as the girl's lips shown in Figure 3, where it is hard to distinguish between various shades of red, the color selection tool is useful for clearly marking where paint should be added.

To hide the colors of disinterest, an additional set of background compensation images are generated during calibration to create the appearance of a checkered pattern throughout the entire canvas. Following color selection, background compensation images are composited with regions of the layer-specific compensation images whose colors are similar to the selected pixel within a user-specified tolerance. This tolerance is adjustable using a foot pedal to interactively expand or contract the colored region of interest.

By interacting with preview and color selection modes during the execution of a layer, the artist is able to systematically complete their task. In order to assess the progress made in painting a layer and, consequently, the overall progress in creating a painting, the artist may switch the projectors off at any time using *blank mode*. The included video shows an example of a region before, during, and after brushstrokes have been applied to complete a layer.

While preview and color selection modes showe the artist where to apply paint, *orientation mode* shows the artist how to apply it. A set of guidelines show the orientation that brushstrokes should be applied to get a desired brushstroke texture as illustrated in Figure 4. *Texture highlight mode* enhances the visibility of paint texture by projecting full brightness from one projector at a time.

3 Sources of Layers

While it is possible for a painter to execute an arbitrary painting by toggling between blank and preview modes, the key to our system is the ability to guide the painter through the complete painting

Figure 3: **Left**: Layer 4 out of 4 in preview mode with box highlighting lips **Middle**: Closeup on girl's lips **Right**: Girls lips following color selection

process. This is another difference between our system and a conventional art projector. A number of painting processes may be designed for guiding a user to paint in layers. In particular, layers can be created manually using images captured from experienced artists or generated automatically using painterly rendering systems.

Artist-Generated Layers Layers may be captured by recording the painting process of an experienced artist. Key frames from a video of a progressing painting, for example, can be manually processed with an image editor to segment the snapshots into regions that should or should not be painted. For painting operations that manipulate the painting aside from applying new paint, such as blending or removing paint, orientation guidelines may also be manually created for use in orientation mode, as was done for the example in Figure 4. In addition to this capture approach, painting manuals or how-to guides can be scanned in and registered using standard image matching techniques.

Computer-Generated Layers We use the painterly rendering system of [Hays and Essa 2004] to automatically synthesize layers for a painting given an input photograph. We chose this system for its ability to generate layers from an input image by rendering brushstrokes along contours output by edge detections at varying frequency bands. Low frequency edges are rendered with wider brushstrokes and high frequencies are rendered with narrower ones. Figure 7 shows an example of four layers generated by their renderer. One advantage of using their system for our application is their generation of contours for orienting brushstrokes during rendering. Our system uses the generated contour maps for display in orientation mode.

4 Creating a Display on a Painted Canvas

This section describes how our system displays guiding light directly on the canvas. By augmenting the canvas with display capabilities, the artist can easily see where and how brushstrokes should be applied to the painting using the interaction modes presented in 2.1.

4.1. Multi-Projector Adaptive Display

To create a multi-projector adaptive display, two (or more) projectors are placed at an oblique angle with respect to the display surface. This approach is based on previous work in using multiple projectors to eliminate shadows and blinding light for front-projected displays [Cham et al. 2003]. By overlapping and aligning the displays, each pixel may be illuminated from multiple paths of

Figure 5: **Upper Left**: canvas before compensation. **Upper Right**: desired appearance. **Middle Left**: projector 1 compensation Image. **Middle Right**: appearance with projection of compensation image from projector 1 and black from projector 2. **Lower Left**: projector 2 compensation image. **Lower Right**: final canvas appearance with projection of compensation images from respective projectors.

light, thereby increasing the dynamic range of the display to support our method of photometric adaptation, which is addressed in Section 4.2.

To align the projectors, each projector's output is warped according to the geometry of the projector-canvas setup. A simple geometric calibration step is needed to automatically estimate the required warps. We assume the canvas surface is planar, so homographies are used as the projection matrices on the graphics hardware [Cham et al. 2003]. Each projector's homography maps pixels in projector space to the canvas surface. Following radial distortion correction of a camera, a series of dots are projected onto the canvas and measured with the camera to automatically calibrate the required warps for each projector.

4.2. Photometric Adaptation

In order to control the appearance of the canvas, our system must account for the spatially varying reflectance of a painted canvas. Any image projected onto the canvas will be modulated by the reflectance of the paint and therefore create an undesired appearance as shown in the included video. To achieve a desired appearance, we must process an input image to create a compensation image for each projector to project.

We extend a simple method for adapting a projected display to a surface with varying reflectance [Nayar et al. 2003] by employing multiple projectors that are positioned beside the artist instead of directly in front of the canvas. The algorithm works by projecting an initial input image and iteratively adjusting image intensities using visual feedback. Starting with all projectors projecting black, each projector iteratively reduces compensation error, the difference between desired and measured intensities for each pixel and channel independently, according to the proportional feedback law $P_{i+1} = k(I - C_i) + P_i$, where P_i is the compensation image for iteration i, I is the desired appearance image, C_i is the surface-aligned camera image for iteration i, and k is gain. Once the error has dropped below a threshold tolerance, a completion mask is toggled for the finished pixel to avoid further adjustment of its compensation intensity. Adaptation halts after the change in error for all pixels has stabilized or a maximum number of iterations have executed. Following adaptation, the final compensation image for the current projector is projected and adaptation begins for the next projector. Each subsequent projector reduces error for the remaining pixels that have not met the target intensities for each channel. Figure 5 illustrates the compensation process for 2 projectors positioned as in Figure 2. Clearly, the appearance of the canvas is closer to the desired image with two projectors than one.

The camera is placed directly in front of the canvas behind the user's head and serves as a reasonable proxy for the human viewer. The camera's exposure must also be set such that all or most target intensities can be achieved. If the shutter speed is too fast and we desire very bright intensities with respect to darker pixels in the final appearance, we would require a very bright light source to measure the target intensity. Conversely, if the shutter speed is too slow and the desired image has dark pixels, the environmental lighting measured alone when projecting black from all projectors may cause too bright a measurement. We account for this by hand-adjusting the exposure for each photometric calibration.

5 Results and Discussion

Figure 6 shows three paintings created using our system by three novice artists who had never painted in oils before. Each painting took an average of 5 hours to create using our system. We observed the painting process for these artists and identified the following trends:

First, two of the subjects exhibited initial hesitation in applying the brushstrokes directly on top of the displayed virtual brushstrokes. For the two impressionist style paintings in Figure 6, for example, both artists applied the paint in very small and slow brushstrokes despite the implicit instruction to paint with quicker and more sweeping brushstrokes as visually suggested in preview, color selection and orientation modes.

Second, as the novices' initial hesitations faded and they switched between interaction modes more frequently, task execution speed increased. This indicates that they learned how to apply regions of color in a layer in a more effective manner and, as a result, became more confident in their ability to accomplish painting goals.

Third, as the paintings progressed, all three users switched to color selection mode more frequently. In one case, the artist repeatedly re-adjusted the color similarity tolerance for each color selection before applying a new color to the canvas. This enabled him to grow or shrink the layer segmentation until it appeared to conform to contiguous brushstroke areas as opposed to pieces of brushstrokes resulting from color variation across the brushstroke. This behavior suggests the need for a more sophisticated means of detecting and segmenting brushstrokes for color selection mode.

We were initially concerned about the potential negative effects of glare and shadows on the subjects in our experiment. Glare caused by projecting light onto wet oil paint could both hinder the ability to control the appearance of the canvas using photometric compensation and annoy users of our system. Shadowing on the display due to projector occlusions by the artist could prevent the effective use of interaction modes for painting guidance at the color application and manipulation level. We found that by positioning our projectors at oblique angles, we were able to reduce both of these effects in practice. None of the artists reported any discomfort caused by glare or shadows.

6 Conclusion and Future Work

In this paper, we presented a novel interactive system for guiding artists to paint using traditional methods and tools. We demonstrated how a multi-projector adaptive display can support artistic painting by guiding users according to traditional painting techniques taught in artist's manuals. Furthermore, we presented a set of five interaction modes for a canvas-centric interface which supports a traditional layer-based approach to painting.

In future work, we plan to add additional functionality to our painting system. For example, no assistance is provided for the complex task of color mixing and matching. Artists are expected to mix paint on their own with only the assistance of layer printouts for testing mixed colors before application.

In addition to improving the painting system, we are considering extending the painting interaction techniques presented in this paper to other areas of the fine arts. Multiple projectors could guide a sculptor to preview subtractions to a block of marble, for example, or by visualizing subtraction progress in real-time. Just as layers were used to build up the composition of a painting in this system, a sculpting system could guide an artist in a hierarchical broad-to-fine chiseling approach.

Figure 6: 3 paintings made using our system by 3 painters who had never painted in oil before.

7 Acknowledgments

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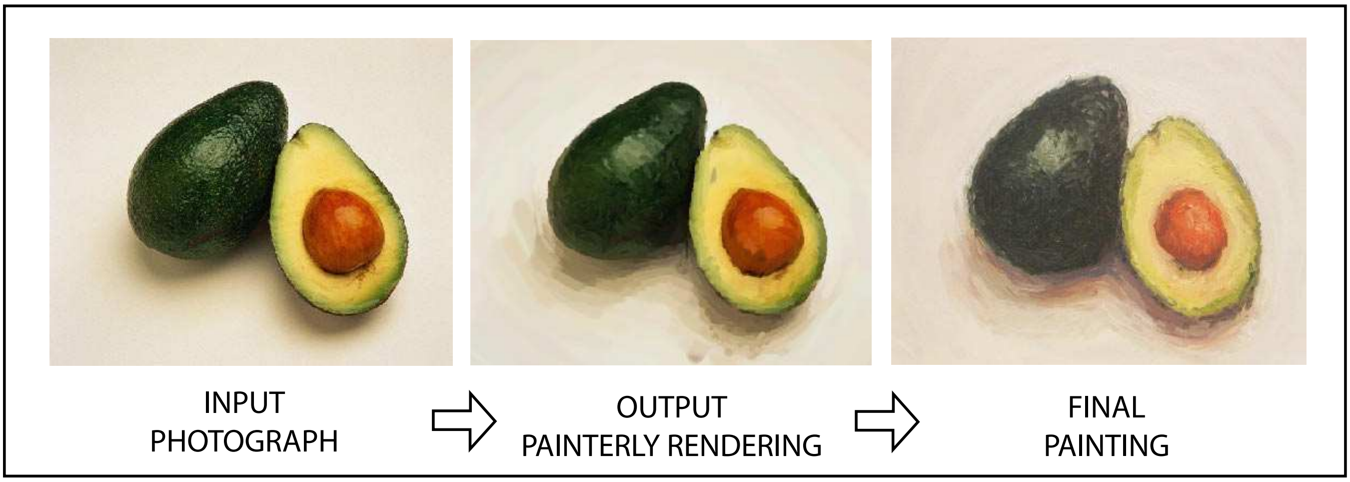

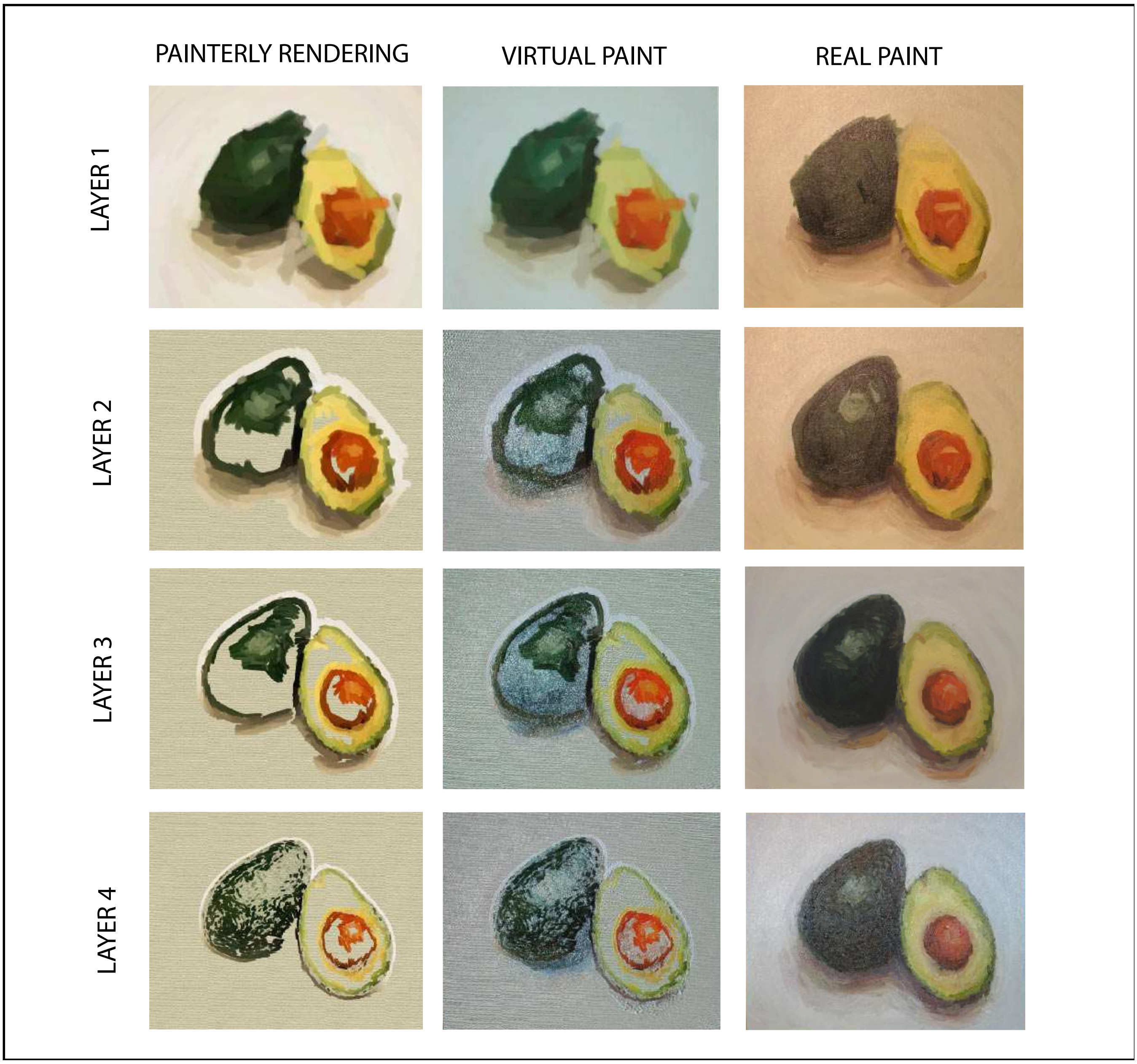

Figure 7: **Top**: Example painting of an avocado created using our interactive painting system. This example uses a painterly renderer, whose output is displayed in the center, to guide the user to paint the final painting (right) given an input photograph (left). **Bottom**: Sequence of four layer images generated using the painterly renderer. The user can paint on the canvas with the aid of a number of interactive modes. The middle column shows the appearance of the canvas in *preview* mode as captured by a digital camera with auto-exposure turned on. The right column shows the painter's progress made after completing each layer, viewable at any time in *blank* mode.